INFLUENCE OF ALKALI RESISTANT (AR) GLASS IN PORCELAIN CLAY FOR VITRIFIED CLAY PIPES

MUHAMMAD IKHMAL BIN HANAPI

A thesis submitted in
fulfilment of the requirement for the award of the
Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

DECEMBER 2017

For my beloved mother and father

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Assoc. Prof. Dr. Sufizar Binti Ahmad for the continuous support given throughout my Master study. His guidance, patience, motivation and immense knowledge have helped me in completing this thesis succesfully. I would like to extend my gratitude to my co-supervisors Assoc. Prof. Dr. Hariati Binti Taib for her continual professional advices and invaluable supports. Nevertheless, I would like to thank Mr. Abu Bakar Bin Aramjat from Kolej Kemahiran Tinggi Mara Masjid Tanah, ADTEC Taiping and all technicians in Material Science as well as Polymer and Ceramic labratories in Universiti Tun Hussein Onn Malaysia for the guidance provided in utilizing the laboratory equipments. I would also like to acknowledge Universiti Tun Hussein Onn Malaysia and Ministry of Higher Education Malaysia for financial support provide for this research through UTHM Research Contract Grant Scheme Vot U553 and MyBrain15 (My Master). Last but not least, I am forever grateful to my family and friends whom had supported me directly or indirectly throughout this journey

ABSTRACT

The aimed of the present work is to produce porcelain clay reinforced with Alkali Resistant (AR) glass for vitrified clay pipes at minimum sintering temperature. In this study, AR fiberglass as a reinforcement was milled into an average particle size of 90 µm and mixed with porcelain in different weight percentage at 3 wt%, 6 wt%, 9 wt%, and 12 wt%. The sample was prepared by using powder compaction and then fired for 2 hours at 900°C, 1000°C 1100°C and 1200°C. Based on the chemical analysis, it was found that SiO_2, Al_2O_3, Na_2O and K_2O is the significant element to produce the material. Result of thermal analysis shows that sintering start occurs at 900°C to 1300°C. The result of volume shrinkage, apparent porosity, water absorption, bulk density and flexural strength were recorded for each samples. Scanning electron microscope (SEM) was used to observe the microstructural morphology of samples. It was found that the addition of AR glass can dramatically lowering the apparent porosity as well as water absorption and increase the value of volume shrinkage, bulk density and flexural strength with the rising of sintering temperature. It can be seen that the volume shrinkage is satisfy the typical ceramic shrinkage where is quarter than original dimension which is 31.75%. Based on the result, the favorable properties of porcelain clay sintering were obtained at sintering temperature of 1100°C with addition of 3 wt% AR glass. Thus, the suitable value of apparent porosity, water absorption and density obtained was 0.41%, 6.27% and 2.29g/cm^3 respectively. Meanwhile, the maximum value for flexural strength gained was 76.40MPa. Based on the microstructure image, it can be seen that the reduction of porosity and increasing of glassy phase was corresponded to the addition of AR glass and rising of sintering temperature. In conclusion, the objective of this study were achieve to satisfied the value of vitrified clay pipes standard based on EN 295.

ABSTRAK

Kajian ini bertujuan untuk menghasilkan tanah liat porselin diperkuat dengan kaca Tahan Alkali (AR) untuk kegunaan paip tanah liat pada suhu pensinteran yang minima. Dalam kajian ini, gentian kaca AR yang berfungsi sebagai penguat telah dikisar kepada purata saiz zarah 90 µm dan dicampurkan bersama porselin dengan peratusan berat yang berbeza iaitu 3 wt%, 6 wt%, 9 wt% dan 12 wt%. Sampel dihasilkan melalui teknik pemadatan serbuk dan kemudian dibakar selama 2 jam pada suhu pensinteran 900°C, 1000°C, 1100°C dan 1200 ° C. Berdasarkan analisis kimia, didapati SiO_2, Al_2O_3, Na_2O dan K_2O merupakan unsur penting untuk menghasilkan bahan tersebut. Hasil analisa suhu menunjukkan proses pensinteran boleh berlaku pada 900°C sehingga 1300°C. Nilai bagi analisa pengecutan isipadu, keliangan jelas, kadar penyerapan air, ketumpatan pukal dan kekuatan lentur telah direkodkan bagi setiap sampel. Pengimbasan mikroskop elektron (SEM) digunakan untuk analisa morfologi mikrostruktur pada sampel. Penambahan kaca AR dilihat dapat menurunkan keliangan ketara serta penyerapan air dan meningkatkan nilai pengecutan isipadu, ketumpatan pukal dan kekuatan lentur secara dramatik jika suhu pensinteran meningkat. Analisa pengecutan isipadu memenuhi pengecutan yang biasanya berlaku pada seramik iaitu suku daripada jasad sebelum pensinteran dengan nilai 31.75%. Berdasarkan ujian yang dilakukan, suhu pensinteran pada 1100°C dengan penambahan 3 wt% kaca AR telah menghasilkan nilai keputusan yang dikehendaki. Oleh itu, nilai sesuai bagi keliangan ketara, penyerapan air dan ketumpatan adalah masing-masing 0.41%, 6.27% dan 2.29g/cm^3. Nilai maksima untuk kekuatan lenturan yang diperoleh pula adalah 76.40MPa. Berdasarkan imej mikrostruktur, pengurangan keliangan dan peningkatan fasa kaca dapat dilihat dengan penambahan kaca AR dan peningkatan suhu pensinteran. Secara keseluruhan, objektif bagi kajian ini telah dicapai serta memenuhi nilai piawai yang diperlukan untuk menghasilkan paip tanah liat kekaca berdasarkan EN 295.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLE

LIST OF SYMBOLS AND ABBREVIATIONS

AR	-	Alkali Resistant
E	-	Electrical
S	-	Silica
C	-	Chemical
PEG	-	Polyethylene Glycol
XRF	-	X-Ray Fluorescence
XRD	-	X-Ray Diffraction
SiO_2	-	Silicon dioxide/ Silica/ Quartz
Na_2O	-	Sodium oxide
CaO	-	Calcium oxide
Al_2O_3	-	Alumina
MgO	-	Magnesium oxide
K_2O	-	Potassium oxide
PbO	-	Lead oxide
B_2O_3	-	Boron trioxide
HCl	-	Hydrochloric acid
NaOH	-	Sodium Hydroxide
Zr	-	Zirconia
NA	-	Not Available
wt%	-	Weight percentage
°C	-	Degree Celsius
mm	-	Millimeter
µm	-	Micron meter
kV	-	Kilovolt

mA	-	Mill ampere
MPa	-	MegaPascal
GPa	-	GigaPascal
g/cm^3	-	gram per centimeter cubic
<	-	Less than
α	-	Alpha
β	-	Beta
kN/m	-	Kilonewton per meter
T_g	-	Transition temperature
ICDD	-	International Centre for Diffraction Data
ASTM	-	American Society for Testing and Material

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of research

Nowadays, the discovery of ceramic materials triggered a huge amount of innovative scientific inquiry and advanced technology. In the meantime, ceramics are important for a wide range of scientific and industrial processes because modern ceramics are made to fulfill of some requirements such as the characteristics of a good mechanical and electrical aspects for resistance to high temperatures and chemicals. Ceramic also produced not only by the strength of its size, it is also seen in terms of durability.

As we can see nowadays, the application of pipes can be found everywhere and plays a vital role. In real world application, countless miles of pipes are a low profile part in the infrastructure but it can be important. Normally, pipes are associated with a sector of water and sewage which each year calls up multitudes and large quantities for its application. Pipes for water and sewage were made up from various material such as wood, metal, copper, iron, concrete, ceramic and clay (Marsh, 2009). However, it is important to decide or choose the material of pipes when it comes to designing and installing the pipes for water and sewage system. Recent developments in pipes material have heightened the need for concerning the environment impacts, natural resource depletion and climate change. A key aspect to consider these material is critical because involving the environmental implications (Vahidi *et al.*, 2016).

Generally, industrial and municipal have demanded tough pipes for sewer because this application required good mechanical strength and chemical resistance. There are several materials can be manufactured for sewer pipes such as plastic, cast iron, concrete and ceramic vitrified sewer pipes. But, it can be seen that clay exhibit high resistance to heat, corrosion, abrasion and chemical (El-shimy *et al.*, 2014). The usage of plastic can be harmful or a bad trace over environment and also knowing the limited resources of oil, a review of clay material in sewer system in order to replace plastic have been made out in a past year. This is because clay is an ecological sustainable material for construction based on their properties such as good thermal mass which is very well in keeping temperature consistency. Besides that, by looking back to the Roman civilization, clay is used as sanitation system of their outstanding baths where is complexes one (Salha & Tosa, 2016).

The unique of clay used as pipes in sanitary drainage are their abrasion and corrosion resistance where clay do not deteriorate or oxidize, rust, erode, bend, elongate and shrink. Their raw material is available and cheap which used in production and it is expected their lifetime can exceed 100 years compared by using plastic which is 50 years of life expectancy. Basically the manufacturing process of these pipes involve the mixing of different types of material which is clay and addition of non-plastic such as feldspar commonly act as fluxing agent and grog or flint. After that, the mixture of material is agitated to extrude in a pug mill before drying process takes place. Lastly, the clay is fired at temperatures exceeding 1250°C typically (Sherbiny & Youssef, 2004). Notably infrastructure work and civil engineering projects in UK market, it is to be seen that the most prominent sewerage work dominate by clay drainage company. It is because the important of environmental consideration and greater longevity maintained the continuity of clay as preferred material in sewage production. Other than that, the use of clay has widespread specification in public sector and housing association because of its durability, strength and lack of vulnerable for maintenance procedure and rodent attack which contrast to plastic pipes where high dependency on site practice and good bedding but less inherent strength (Naylor, 2008).

Despite that, the main disadvantage of ceramic materials is when it is subject to mechanical or thermal loading where catastrophic failure or sudden failure occurred because ceramics do not exhibit plastic deformation as metals which is plastically deform due to their high mobility of dislocation. Normally ceramic material was initially subjected to the mechanical action caused by shrinkage where resulting the dimensional change and ceramic cannot deform freely ensue from the restricted displacement of stress. By including the short fibers in low volumetric fraction to the material, it is possible to control the growth of crack and reduce the impact by early age of shrinkage (Barluenga & Hernández-olivares, 2007). However, there has been an increasing interest in producing ceramic composite from glass ceramic systems due to high fluidity of glass forming melts appeared when sintering process in the raw materials to produce low porosity. More than that, the interaction of complex matrix reinforcement will prompt crack deviating and absorbing fracture energy (Gorokhovsky *et al.*, 2015).

It is to be seen that Alkali-resistant glass (ARG) have been widely used in civil engineering or construction. Normally, it was applied to reinforce cementitious matrices (Rothe & Plonka, 2006). The permissible amount of AR Glass fibre in concrete reinforced has affect better performance of flexural strength, compression and energy absorption to the matrices (Alam *et al.*, 2015). Moreover, the application in construction such as sewage pipes, structural components in chemical plants, boats, and others frequently exposed to cement hydration. Alkali-resistant glass fiber had a potential of corrosion in the alkaline environment formed, which will directly affect the strength stability of the composites and long-term performance (Xiaochun *et al.*, 2017). Table 1.1 provides the use of AR glass in real world application.

Table 1.1: The use of AR glass in real world application (Rabadiya & Vaniya, 2015)

Application	Example of application
Overlays	Roads, Airfields, Runways, Container, Movement and Storage Yards, Industrial Floors and Bridges.
Pre-Cast Concrete Products	Manhole covers and Frames, Pipes, Break-Water Units, Building Floor and Walling Components, Vaults etc
Hydraulic and Marine Structures	Dams, Spillways, Aprons, Boats and Barges, Sea Protection Works
Defense and Military Structures	Aircrafts Hangers, Missile and Weaponry Storage Structures, Blast Resistant Structure

Overall, this study focuses on reinforcement incorporation in the raw ceramic materials which is commercial porcelain clay as matrix for vitrified clay pipes. The objective of the present work is to improve physical properties and mechanical strength of ceramic material with incorporation of the glass material which can be applied in manufacturing vitrified clay pipes in future. Besides that, the identification in minimizing the processing parameter is significant as purpose of this research.

1.2 Problem statement

A study by Vahidi *et al.*, (2016) stated that the main issue regarding to clay material for sewer application are coming from logistic in which involving with transportation and installation. It is the biggest challenge for workers to handle a heavy weight materials mobility. Therefore, by reducing its densities slightly during sintering while having a favorable strength were keys to overcome a logistic complication (García-ten *et al.*, 2012).

Besides that, its brittle properties have become crucial drawback where crack or leakage would potentially affect the pipes while carrying vehicle driveways and when maintaining the pipes. Hence, the brittle properties can be enhanced promisingly by including powder glass or whiskers in which producing ceramic composite (Gorokhovsky *et al.*, 2015). It is to be known that clay pipes for sewer application was made by mixing three main formulations which are terra cotta clay, grog and feldspar. As for mixing and manufacturing these material is not feasible. Besides that, corrosive product was also the most frequent stated problems in sanitary sewer which incorporate in producing blockage to the pipe flow and affecting the durability and longevity of the pipes while in services (Bruce, 2011). Thus, the use of porcelain can be seen potentially to overcome the drawback stated previously. It is to be known that porcelain is commonly used in chemical ware because it was comprised from tri-axial material and has very least porosity (vitreous) resulting low water absorbency as well as high strength compared to other white ware material. Furthermore, the properties of water and stain proof can eliminate the blockage problem and less maintenance (Keith & Goswani, 2005).

This research has chosen Alkali Resistant (AR) glass for reinforcement and also possibly act as fluxing agent. Normally, AR glass is commonly used in construction field because of the availability, suitability in producing lightweight application which can also change brittle properties into plastic properties as well as improving its flexural strength (Xiaochun *et al.*, 2017). The use of AR glass in concrete usually shows a good result in compressive strength because of the shear deformation at the interface of fiber-matrix produces a load carrying capacity contribution to the material and also increased strength (Alam *et al.*, 2015). As reported by Ghugal, (2006) the inclusion of Alkali Resistant (AR) glass can retain the strength of Portland cement and concrete for long periods. Previous attempt have found that the use of E-glass fibers in concrete was disadvantageous because the durability and strength properties of concrete is affected by the attack of alkali on the fibers of hydrated cement paste (Rabadiya & Vaniya, 2015).

In manufacturing a ceramic product, the final properties are depending on the sintering process due to the involving physico-chemical reactions. Therefore, it is important to consider the raw material preparation, drying condition and firing cycle to ensure the better development of phase and microstructure complexity because it will have affected the product qualities (Bragança & Bergmann, 2004). Additionally, there has been interest in increasing the use of fluxing agent such as feldspar currently. This is because fluxing agent acts to low the melting temperature resulting a glassy form in which accelerate the expansion of particle to aid the bonding of different component mixtures for ceramic bodies (El-shimy *et al.*, 2014). The present work aimed to show the correlation between sintering temperature, processing parameter and properties of porcelain clay reinforced AR glass with reference to glassy phase formation.

Hence, it is proposed that the use of porcelain would reduce the blockage cause by corrosive product. In other hand, the inclusion of AR glass to porcelain clay is expected to achieving favorable properties of a material as shown in Table 1.2.

Table 1.2: Standard value performance for vitrified clay pipes

Properties	Vitrified clay pipes standard value (EN 295)
Density	1.70g/cm^3 - 2.24g/cm^3
Water absorption	2% - 8%
Flexural strength	15 MPa – 40 MPa

It is important for all materials to have a benchmark value for its application. This is because the benchmarking value will ensure the performance of the product. As for this study, the properties of porcelain clay with AR glass addition should satisfy the value provided by Harmonized European and Egypt standard for vitrified clay pipes (EN 295) as well as typical value of ceramic material that have been established by other researcher.

1.3 Objective of research

i. To produce porcelain clay with reinforcement of AR glass for vitrified clay pipes.
ii. To characterize the physical and mechanical properties of porcelain clay based on addition of AR glass and various sintering temperature.
iii. To determine the effect of AR glass addition towards porcelain clay in achieving standard value of vitrified clay pipes at minimum sintering temperature.

1.4 Scope of research

i. The commercial porcelain clay was used as the matrix of the material with particle size less than 90 µm.
ii. The reinforcement used for this research is milled fiberglass type Alkali Resistant (AR) at 3wt%, 6wt%, 9wt%, 12wt% with average particle size of 90 µm.
iii. Polyethylene Glycol (PEG) at 1wt% was used as binder in green body formation.
iv. Four sintering temperature for this research were 900°C, 1000°C, 1100°C, 1200°C.
v. The characterization that has been performed were element composition analysis by using X-Ray Fluorescence (XRF), thermal analysis (Thermogravimetric and Differential Thermal), phase identification analysis by using X-Ray Diffraction (XRD), volume shrinkage, microstructure morphology, apparent porosity, density, water absorption and flexural test (3-point bending).
vi. Harmonized European and Egypt standard for vitrified clay pipes (EN 295) were reference for performance of the material

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to ceramic

Normally, metals have subscribed to the belief that it is the main key in engineering material. Nevertheless, ceramic material has long been noted as great interest in a wide range of fields and was more abundant in class of engineering materials. Ceramic is frequently prescribed for its physical and mechanical properties where derives in nature abundantly makes it distinguish from metals. Ceramic comes from the term 'Keramos' which Greek word means as "pottery" or "potter's clay". Besides that, the term originally based on Sanskrit term which means "to burn". The early used of 'Keramos' in Greek describing a meaning of product which containing clay material is obtain from heating or firing process. Therefore, all products which are made by fired clay such as bricks, tableware, sanitary ware and refractories were referred as the term 'Keramos' extensively. Ceramic materials normally affiliate as mixed bonding where derives from a combination of bonding such ionic, covalent and sometimes metallic. Ceramic is made up by assortment of interrelated atoms where no distinct molecules (Barry & Grant, 2007).

Ceramic also a non-conducting materials for thermally and electrically because the bonding of ceramic do not offer any free electron (Bandyopadhyay & Bose, 2013). Basically, ceramic produce from a compound consist of metal or semimetal and individual or added nonmetal which is inorganic material. Common properties such as high melting temperatures, high hardness, good thermal and electrical insulating characteristic and chemical stability makes ceramic as pivotal role in engineered products (Groover, 2010).

Other than that, there are two types of structure in ceramic compound which are crystalline and amorphous (non-crystalline). Crystalline structure is known as arranged atom packed in 3D array of a periodic fashion. If there are one crystal in crystalline materials, it is referred as single crystal whereas polycrystalline formed if there are many crystal in the structure (Askeland *et al.*, 2010). While amorphous is define as the disorder arrangement or discontinuous long-range order of material atoms. Sometimes it is called as material having a lack of regular or systematic arrangement of non-crystalline solid in relatively large structure (Callister & Rethwisch, 2007). Figure 2.1 shows a different between crystalline and non-crystalline structure for silicon dioxide (SiO_2).

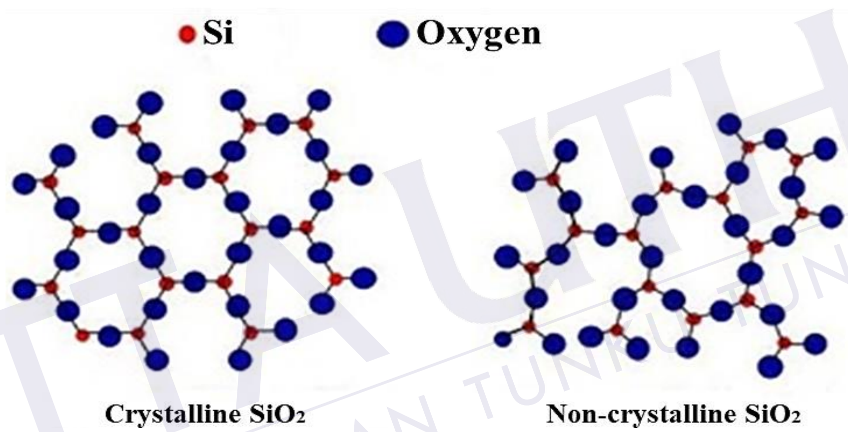

Figure 2.1 : Different of crystalline and non-crystalline structure of silicon dioxide (Callister & Rethwisch, 2007)

Besides that, ceramic usually characterized based on the abrasion resistance, chemical inertness, brittleness and hardness because it is exposed to rasping environment compared to polymers and metal. Regarding to its mechanical behavior, the disadvantages of ceramic materials is their brittle properties even though they are hard. Hence, ceramic is classified widely into oxide and non-oxide ceramics to display their different characteristic (Kakani & Amit, 2014).

A primary concern of non-oxide ceramics is their superior characteristic such as high stability thermally because of their higher melting temperature manifest high chemical inertness. Other than that, non-oxide ceramic widely used as high performance material where the material includes silicide (molybdenum disilicide), carbides (silicon

REFERENCES

Alam, A., Ahmad, I., & Rehman, F. (2015). Experimental Study on Properties of Glass Fibre Reinforced Concrete. *Journal of Engineering Trends and Technology*, *24*(6), 297–301.

Alim, M. A., & Smith, C. C. (2002). *Advanced ceramic technology for space applications at NASA-MSFC*. *Statewide Agricultural Land Use Baseline 2015* (Vol. 1).

Amarnath, A., Goel, A., Tulyaganov, D. U., Kapoor, S., Pradeesh, K., Pascual, M. J., & Ferreira, J. M. F. (2013). Study of calcium magnesium aluminum silicate (CMAS) glass and glass-ceramic sealant for solid oxide fuel cells. *Journal of Power Sources*, *231*, 203–212.

Askeland, D., Fulay, P., & Wright, W. (2010). *The Science and Engineering of Materials*. *The Science and Engineering of Materials* (6th ed.). Cengage Learning, Inc.

Bandyopadhyay, A., & Bose, S. (2013). *Characterization of Biomaterials*. Elsevier Science.

Barluenga, G., & Hernández-olivares, F. (2007). Cracking control of concretes modified with short AR-glass fibers at early age . Experimental results on standard concrete and SCC, *37*, 1624–1638.

Barry, C. C., & Grant, N. M. (2007). *Ceramic Materials : Science and Engineering* (Vol. 2). Springer New York.

Barsoum, M., & Barsoum, M. W. (2002). *Fundamentals of Ceramics*. Taylor & Francis.

Becker, F. H., & Gmbh, R. (2011). *Debinding processes*. *SACMI*.

Bernardo, E., Esposito, L., Rambaldi, E., Tucci, A., & Hreglich, S. (2008). Recycle of waste glass into "glass-ceramic stoneware." *Journal of the American Ceramic Society*, *91*(7), 2156–2162.

Boch, P., & Nièpce, J. C. (2010). *Ceramic Materials: Processes, Properties, and*

Applications. Wiley.

Brady, G. S., Clauser, H. R., & Vaccari, J. A. (1997). *Materials Handbook: An Encyclopedia for Managers, Technical Professionals, Purchasing and Production Managers, Technicians, and Supervisors*. McGraw-Hill.

Bragança, S. R., & Bergmann, C. P. (2003). A view of whitewares mechanical strength and microstructure. *Ceramics International*, *29*(7), 801–806.

Bragança, S. R., & Bergmann, C. P. (2004). Traditional and glass powder porcelain: Technical and microstructure analysis. *Journal of the European Ceramic Society*, *24*(8), 2383–2388.

Britt, J. (2007). *The Complete Guide to High-Fire Glazes*. Lark Books.

Bruce, M. H. (2011). *Comparative Properties and Service Life of Pipes Used as Sanitary Sewers*.

Callister, W. D., & Rethwisch, D. G. (2007). *Materials science and engineering: an introduction* (Vol. 7). Wiley New York.

Campbell, F. C. (2010). Chapter 1: Introduction to Composite Materials. *Manufacturing Processes for Advanced Composites*, 30.

Chawla, K., & Thekwani, B. (2013). Studies of Glass Fiber Reinforced Concrete Composites. *International Journal of Structural and Civil Engineering Research*, *2*(3), 3–9.

Chiou, J. M., & Chung, D. D. L. (1993). Improving the temperature resistance of aluminium-matrix composites using an acid phosphate binder. *Journal of Material Science*, *28*, 1435–1446.

Dal, M., Cantavella, V., Sánchez, E., Hotza, D., & Gilabert, F. A. (2013). Fracture toughness and temperature dependence of Young's modulus of a sintered albite glass. *Journal of Non-Crystalline Solids*, *363*, 70–76.

Dhanaraj, G., Byrappa, K., Prasad, V., & Dudley, M. (2010). *Springer Handbook of Crystal Growth*. Springer Berlin Heidelberg.

Djangang, C. N., Kamseu, E., Elimbi, A., Lecomte, G. L., & Blanchart, P. (2014). Net-Shape Clay Ceramics with Glass Waste Additive. *Materials Sciences and Applications*, *5*(June), 592–602.

El-shimy, Y. N., Amin, S. K., El-sherbiny, S. A., & Abadir, M. F. (2014). The use of cullet in the manufacture of vitrified clay pipes. *Construction and Building Materials*, *73*, 452–457.

Eyring, G. (1988). Advanced Materials by Design. *Congress of The United States - Office of Technology Assessment*, (June).

Fahrenholtz, W. G. (2004). *Ceramic Engineering 111 Sintering*.

Fatih, A., & Anton, R. (2012). Nanoparticle Assisted Coagulation of Aqueous Alumina Suspensions. *Material Research*, *15*(1), 81–89.

Ferrer, S., & Mezquita, A. (2015). Estimation of the heat of reaction in traditional ceramic compositions. *Applied Clay Science*, *108*(May).

Firat, F. A., Ercenk, E., & Yilmaz, S. (2012). Effect of substitution of basalt for quartz in triaxial porcelain. *Journal of Ceramic Processing Research*, *13*(6), 756–761.

Funke, H., Gelbrich, S., Kroll, L., Funke, H., Str, R., & Ash, C. F. (2016). The Durability and Performance of Short Fibers for a Newly Developed Alkali-Activated Binder, 1–8.

Galvao, A. C. P., Farias, A. C. M., & Mendes, J. U. L. (2015). Characterization of waste of soda-lime glass generated from lapping process to reuse as filler in composite materials as thermal insulation. *Ceramica*, *61*, 367–373.

García-ten, J., Saburit, A., Bernardo, E., & Colombo, P. (2012). Development of lightweight porcelain stoneware tiles using foaming agents, *32*, 745–752.

Ghillanyova, D. G. and K. (2010). *Ceramics Science and Technology Volume 2: Properties. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim* (Vol. 2–4).

Gomez, A., & Guardiola, J. (1996). The influence of stability of raw materials used in sizings for E and AR fiberglass manufacture. *Polymer Degradation and Stability*, *51*(October), 361–365.

Goring, H. (2015). Pottery Making Illustrated. In *The American Ceramic Society*. Charlie Spahr.

Gorokhovsky, A. V., Escalante-Garcia, J. I., Sanchez-Valdes, E., Burmistrov, I. N., & Kuznetsov, D. V. (2015). Synthesis and characterization of high-strength ceramic composites in the system of potassium titanate – Metallurgical slag. *Ceramics International*, *41*(10), 13294–13303.

Groover, M. P. (2010). *Fundamentals of Modern Manufacturing. Materials, Process and*

Systems (Fourth Edi, Vol. 4). John Wiley & Sons, Inc.

Hansen, T. (2015). Na2O (Sodium Oxide, Soda). Retrieved from https://digitalfire.com/4sight/oxide/na2o.html

Insights, T. (2013). Ceramic Matrix Composites – an Alternative for Challenging, *1*, 45–49.

Iqbal, Y., & Lee, W. E. (2000). Microstructural Evolution in Triaxial Porcelain. *Journal of the American Ceramic Society*, *83*(189015), 3121–3127.

Jorge, M.-M., Rincón, J. M., & Romero, M. (2010). Mullite development on firing in porcelain stoneware bodies. *Journal of the European Ceramic Society*, *30*(7), 1599.

Jumali, M. H., Mt Said, M. R., Wee, N. Y., Yahaya, M., & Mat Salleh, M. (2010). Kelakuan Pengesanan Tekanan Bagi Seramik Natrium Bismut Titanat. *Sains Malaysiana*, *39*(4), 621–626.

Kadhim, K. M. J., Alwan, A. A., & Abed, I. J. (2011). Simulation of Cold Die Compaction Alumina Powder. *Trends in Mechanical Engineering and Technology*, *1*(1), 1–21.

Kakani, S. L., & Amit, K. (2014). *Engineering Materials* (Vol. 1). New Age International Publisher.

Kamseu, E., Leonelli, C., Boccaccini, D. N., Veronesi, P., Miselli, P., Pellacani, G., & Melo, U. C. (2007). Characterisation of porcelain compositions using two china clays from Cameroon. *Ceramics International*, *33*(5), 851–857.

Kariappa, M. ., & Shete, G. . (2016). Experimental study on the performance of alkali resistant glass fiber reinforced concrete. *International Journal of Scientific Development and Research*, *1*(5), 127–133.

Keith, F., & Goswani, D. Y. (2005). *The CRC HANDBOOK of Mechanical Engineering* (2nd ed.). CRC Press LLC.

Kim, K., Kim, K., & Hwang, J. (2015). LCD waste glass as a substitute for feldspar in the porcelain sanitary ware production. *Ceramics International*, *41*(5), 7097–7102.

Kim, K., Kim, K., & Hwang, J. (2016). Characterization of ceramic tiles containing LCD waste glass. *Ceramics International*, *42*(6), 7626–7631.

Kogel, J. E. (2006). *Industrial Minerals & Rocks: Commodities, Markets, and Uses*. (M. Society for Mining and Exploration (U.S.), Ed.). Society for Mining, Metallurgy, and Exploration.

Krausova, K., Gautron, L., Karnis, A., Catillon, G., & Borensztajn, S. (2016). Glass ceramics and mineral materials for the immobilization of lead and cadmium. *Ceramics International*, *42*(7), 8779–8788.

Kume, M. (1981, January 6). Alkali-resistant glass composition. Google Patents. Retrieved from https://www.google.com/patents/US4243421

Lieser, M. (2011). Glass fibre reinforcement type significantly impacts FRP corrosion performance. *JEC Composites Magazines*, (November), 49–51.

Luz, A. P., & Ribeiro, S. (2007). Use of glass waste as a raw material in porcelain stoneware tile mixtures. *Ceramics International*, *33*(5), 761–765.

Mačiulaitis, R., & Malaiškiene, J. (2009). The regulation of structural parameters of ceramics depending on the drying regime. *Journal of Civil Engineering and Management*, *15*(May), 197–204.

Maity, S., & Sarka, B. K. (1996). Development of High-Strength Whiteware Bodies. *Journal of the Europtwn Ceramic Society 16*, *2219*(96).

Manfredini, T., & Hanuskova, M. (2012). Natural Raw Materials in “ Traditional ” Ceramic Manufacturing. *Journal of the University of Chemical Technology and Metallurgy*, *47*(4), 465–470.

Marsh, G. (2009). Composite pipes capture water and sewage markets. *Reinforced Plastics*, *53*(6), 18–21.

Musikant, S. (1991). *What every engineer should know about ceramics* (Vol. 28). CRC Press.

Mustafa, Z., Ishak, N. F., Shamsudin, Z., Sapari, N. F., & Juoi, J. M. (2015). Porous glass-ceramic composite from recycled soda-lime silica glass and charcoal carbon. *Journal of Engineering and Technology*, *6*(2), 143–150.

Naylor, E. (2008). Using clay pipes for sewage and land drainage. *Working with Water(a Filtration with Seperation and World Pumps Publication)*, *1*(2), 36–37.

Olufowobi, J., Ogundoju, A., Michael, B., & Aderinlewo, O. (2014). Clay soil stabilisation using powdered glass. *Journal of Engineering Science and Technology*, *9*(5), 541–558.

Prasad, C. ., Maiti, K. ., & Venugopal, R. (2001). Effect of rice husk ash in whiteware compositions. *Ceramics International*, *27*(6), 629–635.

Rabadiya, S. R., & Vaniya, S. R. (2015). Effect of Recycled Aggregate with Glass Fiber on High Strength Concrete Properties, *3*(1), 735–741.

Rahaman, M. N. (2003). *Ceramic processing and sintering* (Vol. 2). CRC Press.

Rajamannan, B., Ramesh, M., Viruthagiri, G., & Ponnarasi, K. (2011). Chemical Physics Mechanical properties of ceramic whiteware samples with different amounts of quartz addition. *Elixir International Journal*, *33*(33), 2219–2222.

Ranogajec, J., Djuric, M., Radeka, M., & Jovanic, P. (2000). Influence of particle size and furnace atmosphere on the sintering of powder for tiles production. *Ceramics - Silikaty*, *44*(2), 71–77.

Ravikumar, C. S., & Thandavamoorthy, T. S. (2013). Glass Fibre Concrete : Investigation on Strength and Fire Resistant Properties, *9*(3), 21–25.

Rawlings, R. D., Wu, J. P., & Boccaccini, A. R. (2006). Glass-ceramics: Their production from wastes-A Review. *Journal of Materials Science*, *41*(3), 733–761.

Richerson, D., Richerson, D. W., & Lee, W. E. (2005). *Modern Ceramic Engineering: Properties, Processing, and Use in Design, Third Edition*. Taylor & Francis.

Riedel, R., & Chen, I.-W. (2015). Powder Compaction by Dry Pressing. In *Ceramics Science and Technology: Volume 3: Synthesis and Processing*, *First Edition* (Vol. 3, pp. 1–34). Wiley-VCH Verlag GmbH & Co.

Ring, A. T. (1996). *Fundamentals of Ceramic Powder Processing and Synthesis*. Elsevier Inc.

Romero, M. (2008). J. Martín-Márquez, J. Ma. Rincón and M. Romero, Effect of firing temperature on sintering of porcelain stoneware tiles, *34*, 1867–1873.

Rothe, C., & Plonka, R. (2006). Nano Surface Structuring Of Alkali-Resistant Glass Fibres For Multifunctional Effects Methods. In *1st International Conference Textile Reinforced Concrete* (pp. 67–76).

Salehi, M., & Salem, A. (2010). Porosity-strength correlations in ceramic Raschig ring: Effects of sintering temperature and water content. *International Journal of Applied Ceramic Technology*, *7*(6), 918–924.

Salha, R., & Tosa, F. V. (2016). Looking for Oil-free Building Materials Clay Pipes to Replace Polymer Pipes. *Procedia Technology*, *22*(October 2015), 343–350.

Saravanan, L., & Subramanian, S. B. (2012). The importance of zeta potential in ceramic processing [1] Alumina. *Malvern Zetasizer Nano Application Note*, (1), 1–3.

Serra, M. F., Conconi, M. S., Suarez, G., Aglietti, E. F., & Rendtorff, N. M. (2015). Volcanic ash as flux in clay based triaxial ceramic materials, effect of the firing temperature in phases and mechanical properties. *Ceramics International*, *41*(5), 6169–6177.

Sherbiny, S. A. El, & Youssef, N. F. (2004). Use of cement dust in the manufacture of vitrified sewer pipes, *24*, 597–602.

Shu, Y. (2014). Preparation and properties of polyethylene glycol-based composites phase changes materials. *Advanced Materials Research*, *1004–1005*, 546–549.

Smith, W. F. (1986). *Principles of materials science and engineering*. McGraw Hill Book Co., New York, NY.

Souza, A. J., Pinheiro, B. C. A., & Holanda, J. N. F. (2013). Sintering Behavior of Vitrified Ceramic Tiles Incorporated with Petroleum Waste. In *Sintering Applications* (p. 73). InTech.

Spiller, M. S., & Jameson, M. (2015). *Dental Ceramics*.

Trivedi, N. C., & Mackenzie, J. D. (1989, May 16). Alkali-resistant glass fiber. Google Patents. Retrieved from https://www.google.com/patents/US4830989

Ustundag, C. B., Tur, Y. K., & Capoglu, A. (2006). Mechanical behaviour of a low-clay translucent whiteware. *Journal of the European Ceramic Society*, *26*(1–2), 169–177.

Vahidi, E., Jin, E., Das, M., Singh, M., & Zhao, F. (2016). Environmental life cycle analysis of pipe materials for sewer system. *Sustanable Cities and Society*, *SCS 462*(G-Model), 8.

Vieira, C. M. F., & Monteiro, S. N. (2007). Evaluation of a plastic clay from the state of Rio de Janeiro as a component of porcelain tile body. *Matéria (Rio de Janeiro)*, *12*(1), 1–7.

Voorhees, K. J., Baugh, S. F., & Stevenson, D. N. (1996). The thermal degradation of poly (ethylene glycol)/ poly (vinyl alcohol) binder in alumina ceramics. *Thermochimica Acta*, *274*, 187–207.

Xiaochun, Q., Xiaoming, L., & Xiaopei, C. (2017). The applicability of alkaline-resistant glass fiber in cement mortar of road pavement : Corrosion mechanism and performance analysis. *International Journal of Pavement Research and Technology*.

Yanagida, H., Kōmoto, K., & Miyayama, M. (1996). *The chemistry of ceramics*. Wiley.

Yetmez, M., Erkmen, Z. E., Kalkandelen, C., Ficai, A., & Oktar, F. N. (2017). Sintering effects of mullite-doping on mechanical properties of bovine hydroxyapatite. *Materials Science & Engineering C*, *77*, 470–475.